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14 September 2006

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SUBJECT: AFCEE 4P F41624-03-D-8595; Task Order 0384
MMR SPEIM/LTM/O&M Program
CDRL #A001H
Final Fuel Spill-28 2005 Plume Update Technical Memorandum

Dear Mr. Davis:

As directed by the Air Force Center for Environmental Excellence, CH2M HILL is hereby distributing copies of the *Final Fuel Spill-28 2005 Plume Update Technical Memorandum* dated September 2006. Enclosed are seven bound copies, one unbound copy and seven compact disc (CD) copies. Copies are also being sent to the appropriate agencies.

Jon Davis is the Air Force point of contact for this project and may be reached at (508) 968-4670, extension 4952.

Sincerely,

CH2M HILL

Patricia de Groot, P.G., L.S.P.
Program Manager

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Massachusetts Military Reservation

Final Fuel Spill-28 2005 Plume Update Technical Memorandum

September 2006

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ACRONYMS AND ABBREVIATIONS

AFCEE	Air Force Center for Environmental Excellence
BRL	below the reporting limit
CSM	conceptual site model
CWSW	Coonamessett Water Supply Well
EDB	ethylene dibromide
ETD	extraction, treatment, and surface water discharge
FS-28	Fuel Spill-28
ft^3	cubic feet
ft bgs	feet below ground surface
ft/day	feet per day
ft msl	feet mean sea level
gpm	gallons per minute
lbs	pounds
MMCL	Massachusetts Maximum Contaminant Level
MMR	Massachusetts Military Reservationm
SPEIM	system performance and ecological impact monitoring
SWP	shallow wellpoint
µg/L	micrograms per liter

1.0 INTRODUCTION

This technical memorandum presents a plume update for the Fuel Spill-28 (FS-28) plume (Figure 1-1). The plume update is based on data collected between 01 April 2004 through 31 March 2006 under the System Performance and Ecological Impact Monitoring (SPEIM) program. As part of the plume update new data were collected to characterize the uncaptured portion of the plume and the upper boundary of the plume immediately upgradient (i.e., north) of the FS-28 deep extraction well (69EW0001). The data collected during the characterization efforts (e.g., drilling and groundwater sampling) along with the data collected during the routine SPEIM sampling events were used to develop a new plume shell and update the conceptual site model, with a focus on the uncaptured portion (leading edge) of the plume.

This technical memorandum presents data collected through March 2006, however, investigation activities are ongoing (as of May 2006) to better define the hydrogeology in the leading edge area. The ongoing data collection activities are primarily associated with gathering additional hydraulic monitoring data south of the mapped extent of the plume. The extent of the plume has been adequately characterized based on the data presented in this technical memorandum. The data collected during the ongoing investigation will be presented when available to the regulators during technical update meetings.

This investigation was conducted in support of the Air Force Center for Environmental Excellence (AFCEE) Installation Restoration Program at the Massachusetts Military Reservation (MMR) under AFCEE's 4P Contract Number F41624-03-D-8595, Task Orders 0164, 0251, and 0384.

1.1 BACKGROUND

The FS-28 plume is detached from an unknown source area located on the MMR. The FS-28 plume is located south of the MMR in the Town of Falmouth, and extends from immediately north of Boxberry Hill Road to just north of the intersection of Sandwich and Turner Roads (Figure 1-1). The contaminant of concern within the plume is ethylene

dibromide (EDB). The FS-28 plume is defined as the extent of groundwater contaminated with EDB at concentrations exceeding the Massachusetts Maximum Contaminant Level (MMCL) of 0.02 micrograms per liter (µg/L).

Remediation of the FS-28 plume began in October 1997 with the startup of the deep extraction well (69EW0001). In April 1999, the remedial system was expanded with the startup of the shallow wellpoint (SWP) extraction system. The SWP extraction system was installed to intercept shallow EDB contaminated groundwater before it discharged to the Coonamessett River or associated cranberry bogs. The deep extraction well is currently operating at a design flow rate of 550 gallons per minute (gpm) and the SWP system at 200 gpm. The FS-28 extraction, treatment, and surface water discharge (ETD) system removes EDB from the extracted groundwater using granular activated carbon, and discharges the treated effluent to the Coonamessett River via two bubblers.

A portion of the plume is located to the south (i.e., hydraulically downgradient) of the capture zones of the FS-28 remedial system. This leading edge (or uncaptured) portion of the plume was not intended to be captured by the current treatment system (AFCEE 2000). According to early conceptual site models, the relatively low contaminant mass contained in the uncaptured portion of the plume (compared to the main FS-28 plume to the north) would rise in the aquifer and ultimately discharge to the Coonamessett River and associated cranberry bogs (AFCEE 1998b).

Based on 2004 groundwater vertical profiling sample results, the uncaptured portion of the plume, south of Thomas B. Landers Road, contains higher EDB concentrations and is thicker (vertically) than was previously understood. These results led to recommendations in the *Final FS-28 2004 System Performance and Ecological Impact Monitoring Report* to characterize the uncaptured portion of the plume (AFCEE 2004a). The final FS-28 2004 SPEIM report also recommended the characterization of the upper boundary of the plume upgradient (i.e., north) of the deep extraction well (Figure 1-1) using direct push drilling because this boundary could not be well defined based on the data collected at the available well screens.

1.2 REPORT ORGANIZATION

This report consists of six sections and five appendices. The data collection activities included in this technical memorandum are summarized in Section 2. The results of the drilling and monitoring activities and their interpretation are presented in Section 3. An updated conceptual site model is presented in Section 4. Conclusions and recommendations are presented in Section 5 and references are listed in Section 6.

The boring logs for sonic drilling locations are included in Appendix A. Appendix B contains well construction diagrams. Results of grain size analyses for soils collected at the sonic drilling locations are included in Appendix C. The FS-28 plume shell development is presented in Appendix D. Groundwater vertical profile data collected during drilling activities are included in Appendix E.

2.0 DATA COLLECTION ACTIVITIES

The characterization and monitoring data collected to meet the objectives of this plume update included: (1) chemical data from groundwater vertical profiling and lithologic information from the collection of soils samples and/or interpretation of purge water during drilling activities (both conventional and direct push drilling); (2) shallow groundwater quality data collected using a push-point sampler; and (3) groundwater and surface water monitoring data collected through the SPEIM program. Drilling (both conventional and direct push) and push-point sample locations are presented on Figure 2-1. All groundwater and surface water samples were analyzed for EDB using U.S. Environmental Protection Agency method E504.1 at the MMR on-site laboratory. In addition, water quality parameters (temperature, dissolved oxygen, pH, oxidation-reduction potential, specific conductance, and turbidity) were also measured in the field at each groundwater or surface water sample location, or groundwater sampling interval. Hydraulic monitoring locations are depicted on Figure 2-2. Groundwater and surface water chemical monitoring locations are shown on Figure 2-3. Well construction and surface water location information is provided in Table 2-1. The results of these activities and an evaluation of the data are presented in Section 3.0.

2.1 CONVENTIONAL DRILLING

Groundwater vertical profiling and lithologic logging were conducted at three borings advanced to bedrock using the sonic drilling technique (69MW0012A, 69PZ0004A, and 69BH2001). A fourth sonic soil boring (69BH2000) was advanced to approximately 75 feet below ground surface (ft bgs) for geologic characterization of the shallow portion of the aquifer adjacent to the East Thompson bog (Figure 2-1).

Borehole groundwater screening samples were collected at 10-foot intervals from the water table to the base of the overburden at the three borings that were advanced to bedrock. Groundwater samples were not collected from the fourth shallow sonic boring (69BH2000) because groundwater quality had been assessed at two nearby direct push locations (69DP0120 and 69DP0122). Soil samples were collected from each sonic boring for lithologic classification and grain size analysis. Grain size analysis data were

used to verify the field geologist's interpretation and characterization of soil cores. Soil boring logs for these drilling locations are presented in Appendix A. Monitoring wells and/or piezometers were installed at two locations (69MW0012A and 69PZ0004A). Well construction diagrams are presented in Appendix B.

Each boring, well, or piezometer installed during the conventional drilling program were surveyed for horizontal and vertical position in the Massachusetts State Plane Coordinate System North American Datum of 1927 and National Geodetic Vertical Datum of 1929.

2.2 DIRECT PUSH DRILLING

Groundwater vertical profiling was conducted at 32 locations using direct push drilling technology. Five borings were located within the northern portion of the plume, north of deep extraction well 69EW0001, two borings were located within the shallow plume between 69MW1317 and the SWPs, and 25 borings were advanced to characterize the uncaptured portion of the plume south of the SWPs (Figure 2-1). Groundwater vertical profile samples were collected at 10-foot intervals from the water table to refusal. Soil samples could not be collected during groundwater vertical profile sampling with the direct push rig, however, changes in lithology were inferred from the rate of advancement of the drilling rods, and from field observations of purge water turbidity, color and flow rates at each sample interval.

Of the 25 direct push borings advanced in the vicinity of the uncaptured portion of the plume, seven locations were completed with a deep and shallow groundwater piezometer couplet. Only one shallow piezometer screen (69PZ0006B) was installed at direct push drilling location 69DP1006 on the western side of Round Pond (Figure 2-1). Direct push drilling was also used to install monitoring wells 69MW1306C (on the western edge of the West Thompson Bog) and 69MW1317C (on the eastern side of the Upper Baptiste Bog) (Figure 2-1). Construction diagrams for these piezometers and monitoring wells are presented in Appendix B. None of the direct push borings installed north of the deep extraction well (i.e., 69DP0105, 69DP0106, 69DP0107, and 69DP0108) were completed with piezometers or monitoring wells. Based on the data collected at these locations

north of the deep extraction well (presented in Section 3.2.1.1), it was concluded that additional permanent monitoring locations were not required in this area.

The location and elevation for direct push borings were estimated from two-foot contour topographic coverage obtained from a 1997 AFCEE-sponsored mapping project of the MMR area. Locations at which piezometers or monitoring wells were installed were surveyed for horizontal and vertical position in the Massachusetts State Plane Coordinate System North American Datum of 1927 and National Geodetic Vertical Datum of 1929.

2.3 PUSH-POINT SAMPLING

A hand-driven push-point sampler was used to collect shallow groundwater from immediately beneath the western bog ditch of the East Thompson Bog at 16 locations during August 2006 (Figure 2-1). The screened portion of the push-point sampler was typically advanced to an approximate depth of one to two feet below the bottom of the bog ditch. The locations of each push-point sample were estimated from two-foot contour topographic coverage. This sampling was completed to determine whether EDB contaminated groundwater was discharging to the western bog ditch of the East Thompson Bog at detectable levels.

2.4 HYDRAULIC MONITORING

Synoptic water level measurements were collected from a SPEIM network of 47 monitoring wells and piezometers, and one staff gauge located in the vicinity of the FS-28 ETD system in October 2004. Supplemental synoptic water level surveys were conducted at three different times: (1) May 2005 at 31 monitoring wells and piezometers; (2) November 2005 at 43 monitoring wells and piezometers; and (3) March 2006 at 60 monitoring wells and piezometers, and two staff gauges located in the vicinity of the uncaptured portion of the plume. The May and November 2005 synoptic data were collected under "non-flooded" conditions at the cranberry bogs and the March 2006 synoptic data were collected when the cranberry bogs were flooded for frost protection. The FS-28 SPEIM and supplemental hydraulic monitoring locations are presented on

Figure 2-2. Well construction information for all hydraulic monitoring locations is presented in Table 2-1.

2.5 GROUNDWATER CHEMICAL MONITORING

The groundwater data collected in support of this evaluation were obtained under the SPEIM program through the sampling of 65 groundwater monitoring wells or piezometers at 40 locations, the deep extraction well (69EW0001), 96 of the 204 SWPs, four irrigation wells, one irrigation well sentry well, and the Coonamessett Public Water Supply Well (CWSW) (69PWS40960). The CWSW was connected to the Crooked Pond water treatment plant during August 2005 and is no longer being sampled. The sentry wells 69MW1279B and 69MW1279C will continue to be sampled on a quarterly frequency to monitor water quality upgradient of the CWSW. Monitoring frequencies varied from monthly, monthly during the cranberry growing season (i.e., April through October), to quarterly, semiannually, or annually depending on the objective of the monitoring. Groundwater chemical monitoring locations are presented on Figure 2-3 and well construction information is included in Table 2-1.

2.6 SURFACE WATER CHEMICAL MONITORING

Between March and November 2005 surface water quality was monitored at 27 locations within the Coonamessett River and from cranberry bog ditches in bogs located between Hatchville Road and Pond 14 (Figure 2-3). Prior to June 2005, surface water locations were monitored at monthly, quarterly or annual frequencies depending on the proximity of the plume to the sample location. Because EDB was detected in the surface waters of the Augusta Bog ditches in June 2005, as discussed in Section 3.3.2, the surface water monitoring frequency was increased to monthly for all locations north of Pond 14 through October 2005. The Augusta Bog monitoring location (69SW2001) was also sampled in November 2005. Additionally, surface water quality was monitored near recreational beaches at Coonamessett Pond and Round Pond during April and July 2005 and Jenkins Pond during October 2005. Surface water chemical monitoring locations are presented on Figure 2-3 and location information is included in Table 2-1.

3.0 RESULTS AND ANALYSIS

This section presents the results of the drilling and monitoring activities performed between April 2004 and March 2006 that support this FS-28 2005 plume update. Groundwater hydraulic monitoring results and the supporting precipitation record are presented on Figure 3-1, Figure 3-2, Figure 3-3, Figure 3-4, Figure 3-5, and Figure 3-6 and Table 3-1 and Table 3-2; chemical sample results are presented in Table 3-3 and Appendix E; and lithologic information is presented in Appendix A and Appendix C. Plan and cross-sectional views of the FS-28 plume are presented in Figure 3-7, Figure 3-8, Figure 3-9, Figure 3-10, Figure 3-11, and Figure 3-12. Surface water chemical monitoring locations and results are presented in Figure 2-3 and Table 3-4, respectively. Well construction and sampling location information is included in Table 2-1.

3.1 HYDROGEOLOGY

The hydrogeology of the aquifer south of the FS-28 ETD system was characterized using the available historic soil boring logs for 69MW1306A, 69MW1308, 69MW1309, and 69MW1318A; soil boring data collected during this investigation during the advancement of sonic borings 69MW0012A, 69PZ0004A, 69BH2000, and 69BH2001; and from purge rate and water quality data (e.g., turbidity and color) from 32 vertical profiling locations advanced with a direct push rig (69DP0101 through 69DP0131 and 69DP1006). Lithologic descriptions obtained from the sonic borings were the primary basis for the interpretations discussed in the following sections and presented on the cross-sections. However, qualitative information obtained from the review of the purge water data and field observations made during direct push drilling was used to infer changes in lithology.

The generalized lithology is presented in cross-sectional views on Figure 3-8, Figure 3-9, Figure 3-10, Figure 3-11, and Figure 3-12. Detailed descriptions of lithology observed at the sonic drilling locations are presented on the soil boring logs (Appendix A) and incorporate the results of the grain size analyses (Appendix C); purge water characteristics observed at the direct-push locations are presented in Appendix E.

3.1.1 Lithologic Descriptions

In the vicinity of the uncaptured portion of the plume at 69BH2000 and 69BH2001 (Figure 2-1) light yellowish-brown, medium- and fine-grained sands with trace silt were logged from the water table to an approximate elevation of -40 feet mean sea level (ft msl). Observed purge rates during the sampling of screens set in these sands ranged between 12 to 18 gpm. From -40 ft msl to –80 ft msl a unit of grey, fine-grained sand with little silt, interbedded with a dark grey silt or silty fine sand with trace clay was logged. Purge rates in this zone of silty fine sand and silt recorded during the sampling of groundwater ranged between 3.7 and 9.4 gpm. Immediately below the grey silty sand unit, light yellowish-brown to olive-brown, fine- to medium-grained sands with trace silt were logged from -84 to -200 ft msl. Purge rates for these medium to fine sands ranged between 11 and 14 gpm. Although the higher purge rates recorded for the sandier units may have been limited by the capacity of the pump used (i.e., actual purge rates could be higher), a relative comparison of purge rates recorded in the sandier units and the siltier units indicate that hydraulic conductivity contrasts exist between the two lithologic units.

The grey silty fine sand and silt unit observed at 69BH2001 between -40 ft msl and -80 ft msl is at a similar elevation to a greyish-brown silty fine sand with silt seams logged during a previous investigation at 69MW1306A,B (AFCEE 1997). The top of the grey silty fine sand unit was also observed at -40 ft msl at 69BH2000. However, this boring was advanced only to -75 ft msl (with no recovery from -70 to -75 ft msl) to meet the objectives of assessing the geology of the shallow portion of the aquifer near the East Thompson bog. Therefore, the bottom of this silty unit was not defined at 69BH2000. A review of purge water descriptions from direct push locations 69DP0104, 69DP0123, and 69DP0122, which are located adjacent to sonic locations 69MW1306, 69BH2001, and 69BH2000, respectively, indicate that purge water collected from elevations similar to where the grey silty fine sand units are logged in the adjacent cores is typically grey to dark grey and silty with abundant fine sands settling out in the flow-through cell (used to monitor water quality parameters during sampling). Purge water from the medium to fine sands located above or below the silty zone is typically described as light yellow to tan in color and ranges from very silty with trace fine sand to clear.

Dark grey, silty purge water with abundant fine sands was observed at one or more sampling intervals between -31 ft msl and -74 ft msl at most direct push locations advanced in the vicinity of the leading edge area (69DP0104, 69DP0111, 69DP0116, 69DP0112, 69DP0110, 69DP0117, 69DP0123, 69DP0118, 69DP0118, 69DP0131, 69DP0122, and 69DP0121) (Figure 2-1). South of 69DP0131, the presence of the silt layer, as inferred from purge water observations at direct push drilling locations, is less obvious.

The unit of dark grey silt and silty fine sand does not appear to be present as far north or west as sonic location 69MW0012A (Figure 2-1). At this location, light yellowish-brown medium- to fine-grained sands with trace silt was logged from the surface to an elevation of -135 ft msl. These sands are interbedded with thin (less than 5 feet thick) lenses of silt or gravelly sand. A unit of dark grey silt to sandy silt was logged from -135 to -185 ft msl, which is much lower in elevation than the silty unit observed at the borings located to the south and east in the area between the West Thompson Bog and the Coonamessett River (69MW1306AB, 69BH2000, and 69BH2001).

The unit of silt and silty fine sand observed between -40 and -80 ft msl at 69BH2001 and 69MW1306A was not logged at a similar elevation at sonic drilling location 69PZ0004A, which is located to the south near the southwestern corner of Pond 14 (Figure 2-1). The lithology at 69PZ0004A is comprised of light yellowish-brown, medium- to fine-grained sands with trace silt from the surface (17.49 ft msl) to -106 ft msl. An olive-grey silt with trace fine sand and clay was observed between -106 to –148 ft msl, which is at a lower elevation than the grey silty unit observed at 69BH2001. Beneath the relatively uniform silt layer at 69PZ0004A, interbedded grey and olive medium to fine sands with fine sands and silts were observed from -148 to -232 ft msl. Cobbles and poorly sorted gravel was generally observed from -232 ft msl to the bottom of the boring at -282 ft msl.

In summary, the aquifer in the vicinity of the leading edge portion of the plume, between Thomas B. Landers Road and Hidden Pond Way, appears to be comprised primarily of light yellow-brown, medium to fine sands with trace silt that appear to be divided into a shallow aquifer (above approximately -40 ft msl) and a deeper aquifer (below

approximately -80 ft msl) by a fairly continuous unit of grey, silty fine-grained sand interbedded with silt. This grey silty unit (-40 to -80 ft msl) was not observed as far north and west as 69MW00012A or as far south as 69PZ0004A and based on the lithology at 69BH2001 and purge water observations made during advancement of direct push borings, can only be inferred as far south as Hidden Pond Way. Accordingly, because specific lithologic data are lacking, uncertainty remains as to the areal extent and elevation of this grey silty fine sand unit between Hidden Pond Way and 69PZ0004A. The approximate areal extent of this grey silty fine sand unit that appears to be dividing the shallow and deeper sandy aquifer is shown on Figure 2-1. This unit is also illustrated in cross sectional view on Figure 3-9, Figure 3-10, Figure 3-11, and Figure 3-12.

3.1.2 Estimates of Hydraulic Conductivity

Hydraulic conductivity for select lithologic units in the vicinity of the uncaptured portion of the leading edge of the plume were estimated using grain size analyses from specific depth intervals at 69BH2000 and 69BH2001. Hydraulic conductivities were estimated by entering the grain size data into commercial software, SizePerm® (EasySolve Software, LLC, 1998), which then calculated the estimated hydraulic conductivity using either the Hazen or Beyer methods. The Hazen method was used for well sorted sands and the Beyer formula was used for poorly sorted sediments.

The estimated hydraulic conductivities for the well sorted medium to fine sands with little to trace silt that are located above and below the grey silty unit at 69BH2001 range between 25 and 132 feet per day (ft/day), which is similar to the range of hydraulic conductivities previously estimated (18 to 180 ft/day) for sands collected at 69MW1306 (AFCEE 1997). Estimated conductivities for well sorted sands at 69BH2001 are somewhat greater at 140 to 300 ft/day. The estimated hydraulic conductivities for the grey silty fine sand and silt unit observed at 69BH2000 and 69BH2001 range between 2.5 to 19 ft/day. A summary of the data used to estimate these hydraulic conductivity values is included as Table C-1 in Appendix C.

3.1.3 Hydraulic Data

Hydraulic data collected in support of this FS-28 plume update include water levels collected during the routine SPEIM synoptic event on 27 October 2004. This synoptic event included wells near or within the hydraulic influence of the ETD system. The groundwater elevations calculated for the 27 October 2004 synoptic event are presented in Table 3-1.

In addition, a supplemental synoptic event was conducted at wells located around the uncaptured portion of the plume in May 2005. Subsequent to this May 2005 event, expanded synoptic water level surveys were conducted in November 2005 and March 2006 as the leading edge investigation progressed and new monitoring points became available. The May 2005 synoptic data were used for a preliminary assessment of hydraulic conditions near the uncaptured portion of the plume. The results of this assessment were used to guide the placement of drilling locations where piezometers or monitoring wells were installed. The November 2005 and March 2006 synoptic data are the most comprehensive of the three supplemental synoptic data sets and are discussed further in this technical memorandum. Additionally, the November 2005 synoptic data were collected under non-flooded conditions at the Coonamessett River and associated cranberry bogs, while the March 2006 synoptic data were collected when the cranberry bogs were flooded. The SPEIM and supplemental synoptic data are presented in Table 3-1. The groundwater hydraulic monitoring locations are shown in Figure 2-2.

3.1.3.1 SPEIM Synoptic Event

The groundwater contours based on the elevations recorded on 27 October 2004 are presented on Figure 3-1. In addition to these contours based on the observed data, a set of contours based on predicted groundwater elevations using the 2002 FS-28 groundwater model (AFCEE 2003b) are shown on Figure 3-1. The model predicted contours were generated from a steady state simulation with 69EW0001 and the SWP system operating at design pumping rates (i.e., 550 gpm and 200 gpm, respectively).

A review of the contours presented on Figure 3-1 reveals that the horizontal component of hydraulic gradient (horizontal gradient) and direction of flow based on the measured data generally agree with the model-predictions of groundwater flow. Groundwater flow direction in the northern portion of the plume (north of Coonamessett Pond) is generally from north to the south. The direction of groundwater flow is more southwesterly south of Coonamessett Pond. Flow then appears to converge toward the Upper Baptist bogs and deep extraction well 69EW0001.

Groundwater elevations measured in October 2004 systematically dropped at most wells by an average of 0.28 feet compared to the March 2004 data (AFCEE 2004a). This decrease in groundwater elevations is attributed to the periods of lower precipitation that occurred over the region during the summer of 2004 (Figure 3-2).

3.1.3.2 Supplemental Synoptic Events

The lithologic descriptions and hydraulic conductivity estimates collected during this investigation suggest that the aquifer south of Thomas B. Landers Road may be divided into shallower and deeper portions of higher conductivity sands that are separated by a fairly continuous, lower conductivity silty sand unit. Therefore, the November 2005 and March 2006 synoptic data sets were subdivided into a deep groundwater data set (screens deeper than -70 ft msl) and a shallow groundwater data set (screens shallower than -70 ft msl) in an effort to assess groundwater flow above and below this silty unit.

Synoptic data were processed using a contour-mapping program Surfer 8® (Golden Software, 2002) to create initial groundwater contours. The Surfer 8® generated contours were adjusted slightly to eliminate artifacts of the contouring process that would otherwise produce hydrologically unreasonable results. The March 2006 synoptic data included questionable measurements at 69PZ1287A and 69SG0046-04. The groundwater elevation at 69PZ1287A decreased by 4.86 feet between November 2005 and March 2006, and a similar response was not observed at other screens within this well cluster (69MW1287 and 69PZ1287B). Therefore, the depth to water measured at 69PZ1287A in March 2006 is considered to be erroneous and most likely the result of field measurement

error and was removed from the dataset. The water level measurement collected at staff gauge 69SG0046-04 was not used because the elevation of the Coonamessett river at this staff gauge is considered to be the result of flow manipulation with weir boards and not always reflective of the groundwater elevation in the adjacent aquifer. For both synoptic events, groundwater contours for the shallow portion of the aquifer are presented on Figure 3-3 and Figure 3-5, and for the deeper portion of the aquifer on Figure 3-4 and Figure 3-6.

In the vicinity of the uncaptured portion of the plume, the groundwater flow direction in both the shallow and deep parts of the aquifer (i.e., above and below the silty sand unit) south of Thomas B. Landers Road is primarily to the south. Where sufficient data density exists, groundwater flow toward the Coonamessett River in the shallow portion of the aquifer has been mapped to occur only immediately adjacent to the river.

The horizontal gradient in both the deep and shallow portions of the aquifer south of Thomas B. Landers Road are oriented primarily toward the south with a magnitude of approximately 0.002 in both November 2005 and March 2006, which is the same magnitude (0.002) previously calculated for the area immediately north of Thomas B. Landers Road (AFCEE 1997). Based on the pattern of hydraulic head depicted in Figure 3-3, Figure 3-4, Figure 3-5, and Figure 3-6, the horizontal component of hydraulic gradient affecting the uncaptured portion of the plume appears to be relatively uniform spatially and the same magnitude under both flooded and non-flooded conditions. The process of flooding and draining of the bogs appears to have reached steady-state by the time the measurements were made (measurements in November 2005 were approximately six months into the non-flooded period for all but the Augusta Bog, and measurements in March 2006 were approximately two months into the flooded period for the bogs). As a result, while changes in water levels were observed, the hydraulic gradients in the aquifer had equilibrated by the time the measurements were made.

Currently, groundwater elevations west of Pond 14 are unknown. However, additional well/piezometer clusters are currently being installed between Jenkins Pond and Pond 14 as part of the ongoing leading edge investigation (see Section 5.3). Once completed,

groundwater elevation data from these new locations will be collected and incorporated into the conceptual site model.

The vertical components of hydraulic gradient (vertical gradients) at select monitoring well/piezometer clusters located in the vicinity of the uncaptured plume are presented in Table 3-2. As shown on Table 3-2, the vertical gradients were measured between individual screens within a cluster and from deepest to shallowest setting in an effort to characterize the potential for vertical flow that may occur at different depths of the aquifer. However, at many locations the difference in hydraulic potential between closely spaced well screens within a cluster is less than 0.1 feet (i.e., a difference in groundwater elevation of 0.01 ft between 69PZ1302 and 69MW1302 in March 2006), which is likely within the range of field measurement and survey error. Therefore, the resulting vertical gradients at these locations are considered to be so low (less than 1×10^{-3}) as to be immeasurable and that the gradient at these well screens is considered to be primarily horizontal. Those measurements that have a difference in hydraulic head potential of approximately 0.1 foot or more are considered to be reproducible and are discussed below. Well clusters at which a measurable vertical gradient were observed in one or both of the synoptic events are identified in Table 3-2 and are listed as follows: 69MW1296; 69MW1297; 69MW1299; 69MW1302; 69MW1306; 69PZ0004; 69PZ0005; 69PZ0012; 69PZ0017; 69PZ0019; 69PZ0020; 69PZ1301; 69MW1308; 69MW1309; and USFW479 clusters.

Upward components of vertical gradient between the deepest and the shallowest screen setting within a cluster (from deeper aquifer to shallower aquifer) were measured at locations adjacent to the Coonamessett River: 69MW1299, 69MW1309, 69PZ0019, 69MW1301, 69PZ0005, and 69PZ0004; and along the northern portion of the Augusta bog at 69MW1297. Of these locations the maximum upward gradient was measured at the southwestern corner of Pond 14 (69PZ0004) during both synoptic events. The relatively large upward component of vertical gradient measured at 69PZ0004 during both rounds suggests a potential for the upward flow of groundwater in this area. At the remaining locations, the vertical component of hydraulic gradient is either approximately

equal to or an order of magnitude lower (0.0015 to 0.0006) than the horizontal component of gradient (0.002), suggesting that immediately adjacent to the river or ponds there is slight potential for upward flow of groundwater.

Downward vertical gradients between the shallowest and deepest screen settings within a cluster were measured at locations within the footprint of the plume at the southern edge of the Augusta Bogs (69MW1308, 69MW1302, 69MW1306) and at a location in the vicinity of the leading edge of the uncaptured plume (69PZ0017). At these locations, the downward component of vertical gradient, although relatively low in magnitude is an indication that groundwater flow in the vicinity of the plume between Thomas B. Landers Road and 69PZ0017 is primarily horizontal to slightly downward.

In summary, the hydraulic data collected during the two supplemental synoptic events at the leading edge suggest that the horizontal gradient of flow south of the FS-28 ETD system is uniform and primarily in a southerly direction under flooded and non-flooded conditions. The vertical gradients at many locations are very low (less than 1×10^{-3}) therefore the potential for vertical flow (either upward or downward) is minimal (i.e., groundwater flow is primarily horizontal). At those locations where a definitive vertical component of hydraulic gradient was measured, the gradients were slightly upward at clusters located immediately adjacent to the Coonamessett River and Round Pond. Within the footprint of the plume the vertical component of hydraulic gradient at most locations is slightly downward, indicating that the plume is likely to stay at depth in the aquifer south of Thomas B. Landers Road.

3.1.4 Average Linear Velocities

Average linear velocities for groundwater within the well sorted medium to fine sands associated with the shallow and deep portions of the aquifer at the leading edge were calculated using the March 2006 measured horizontal hydraulic gradient of 0.002, an assumed effective porosity of 0.3, and the range of estimated hydraulic conductivities presented in Section 3.1.2. For groundwater in well sorted sands with estimated

hydraulic conductivity values between 104 and 180 feet per day (ft/day), the average linear groundwater velocity is estimated to be between 0.69 and 1.2 ft/day.

3.2 CHEMISTRY DATA

3.2.1 Groundwater

Groundwater data presented in the final FS-28 2004 SPEIM report (AFCEE 2004a) indicated that the FS-28 plume was divided into three distinct lobes: (1) the area of the plume upgradient of the deep extraction well; (2) the lobe migrating towards and being captured by the SWP system; and (3) the southern uncaptured portion of the plume. The 2004 SPEIM report also identified two areas of the FS-28 plume that required additional characterization: (1) the uncaptured portion of the plume; and (2) the area immediately upgradient (or north) of the deep extraction well. In response, direct push drilling was used to further characterize the FS-28 plume in these areas. In addition to the direct push drilling, sonic drilling was employed at four locations to obtain characterization data (i.e., groundwater vertical profile data and/or lithologic data). This section presents the chemical data collected during these additional characterization activities, as well as the monitoring data collected during the routine SPEIM sampling events.

3.2.1.1 <u>Upgradient and in the Vicinity of the Treatment System</u>

This section discusses groundwater quality and trends in the plume areas upgradient and in the vicinity of the groundwater extraction systems. Accordingly, the discussion is focused on the FS-28 plume upgradient (i.e., north) of Coonamessett Pond, between Coonamessett Pond and the deep extraction well (69EW0001), and between the deep extraction well and the SWP system.

Upgradient Plume Monitoring

The extent of the northern (upgradient) portion of the FS-28 plume (north of the western arm of Coonamessett Pond) is monitored annually through the sampling of ten monitoring wells (69MW1271, 69MW1272, 69MW1275, 69MW1400A, 69MW1401,

69MW1403, 69MW1404, 69MW1411, 69MW1416, and 69MW1419) (Figure 2-3). EDB detections at these locations ranged from below the reporting limit (BRL) to 0.104 µg/L (Table 3-3). The trailing edge of the plume is located immediately north of Boxberry Hill Road, as indicated by the sub-MMCL EDB groundwater concentrations reported in the northern most wells 69MW1419 (BRL), 69MW1416 (0.018 µg/L), 69MW1271 (BRL), and 69MW1272 (0.019 µg/L) (Figure 2-3 and Table 3-3). This portion of the FS-28 plume is shown in plan view on Figure 3-7 and in cross-sectional view on Figure 3-8.

In general, EDB concentrations have decreased in the northern portion of the plume with the exception of 69MW1411, which increased slightly from nondetect (AFCEE 2004a) to 0.010 µg/L and 69MW1416, which increased slightly from 0.011 µg/L (AFCEE 2004a) to 0.018 µg/L (Table 3-3).

In-Plume Monitoring in the Vicinity of the Deep Extraction Well

The EDB concentrations in the vicinity of the deep extraction well (69EW0001) are monitored through the sampling of 13 monitoring wells (69MW1284A,B; 69MW1285A,B; 69MW1303A,B; 69MW1304, 69MW1317A,B; 69MW1278, 69MW1283A,B; and 69MW1310) (Figure 2-3). In addition to the monitoring wells sampled, vertical profile groundwater samples were collected at six direct push drilling locations (69DP0101, 69DP0105, 69DP0106, 69DP0107, 69DP0108, and 69DP0109) (Figure 2-1, Appendix E). The locations of the extraction well, vertical profile locations, and the monitoring wells are shown in plan view in Figure 2-1, Figure 2-3, and Figure 3-7. Cross-sectional views of the plume are shown on Figure 3-8 and Figure 3-9.

EDB continues to be detected above the MMCL in groundwater sampled from monitoring wells between the western arm of Coonamessett Pond and the deep extraction well 69EW0001. Generally, EDB concentrations were lower in this portion of the plume than reported in the 2004 SPEIM report (AFCEE 2004a), with the exception of groundwater sampled from 69MW1283A, where the EDB concentration increased from

0.479 µg/L in March 2003 (AFCEE 2004a) to 1.32 µg/L during April 2004, and then decreased to 0.996 µg/L in March 2005 (Table 3-3).

EDB concentrations decreased in groundwater sampled from four wells located within approximately 850 feet and upgradient of the deep extraction well, specifically 69MW1284A,B, 69MW1304, and 69MW1310 (Figure 2-3, Table 3-3). EDB concentrations at 69MW1310 (mid-screen elevation -202 ft msl) decreased from 2.87 µg/L in May 2004 to 1.14 µg/L in April 2005. EDB concentrations detected in samples from 69MW1304 (mid-screen elevation -181 ft msl) declined from 2.84 µg/L in May 2004 to 1.87 µg/L in September 2005.

Monitoring wells 69MW1284A (mid-screen elevation -180 ft msl) and 69MW1284B (mid-screen elevation -216 ft msl) are located approximately 55 feet north (upgradient) of the deep extraction well. The EDB concentration in 69MW1284A decreased from 2.94 µg/L in April 2004 to 2.32 µg/L in September 2005. This well is screened approximately eight feet below the extraction well screen. Samples from monitoring well 69MW1284B contained EDB concentrations ranging from 3.84 µg/L in April 2004 to 2.98 µg/L in September 2005. Relative to the extraction well, 69MW1284B is screened approximately 44 feet deeper. It should be noted that this portion of the plume is within the capture zone of the deep extraction well pumping at the current design rate of 550 gpm (Figure 3-14) (AFCEE 2004a).

Direct push drilling was used to characterize the upper boundary of the plume at four locations upgradient of the deep extraction well (i.e., 69DP0105, 69DP0106, 69DP0107, and 69DP0108) (Figure 2-1, Appendix E). Direct push drilling location 69DP0107 is located adjacent to monitoring well 69MW1283, approximately 1,250 feet north of the deep extraction well. EDB was not detected in the samples collected from this location because groundwater samples could only be collected to a depth of 97 ft bgs (60.5 ft msl) due to the refusal encountered at this depth in the borehole. As a result, this direct push location did not reach the depth required to characterize the top of the plume (Figure 3-8).

The upper boundary of the plume at 69DP0106, which is adjacent to 69MW1310, was observed at an elevation of approximately -120 ft msl (Figure 3-6; Table 3-3). This is shallower than the elevation determined during the installation of 69MW1310 in January 1997 when the top of the plume was detected at approximately -150 ft msl (AFCEE 1997). The upper boundary of the plume at 69DP0105 (which was installed adjacent to 69MW1304 and to the south west of 69DP0106) was encountered at approximately -85 ft msl, which is similar to the elevation determined during the installation of 69MW1304 in 1997 when the plume was observed at approximately -90 ft msl (AFCEE 1997).

The upper boundary of the plume at 69DP0108 (which is adjacent to the 69MW1284A,B well cluster and approximately 250 feet south of 69DP0108) was observed at approximately -136 ft msl. The upper boundary of the plume at this location is now considerably deeper than the elevation of the upper boundary in 1996 (between -88 and -107 ft msl) when 69MW1284 was installed. The vertical collapse of the plume at this location is likely due to the operation of the deep extraction well.

The results of the direct push drilling conducted north of 69EW0001 revealed that the upper boundary of the plume is not at a consistent elevation. The top of the plume is at a similar elevation as observed in 1997 at 69DP0105, shallower at 69DP0106, and deeper at 69DP0108. These results likely indicate that the upper boundary of the plume is influenced by the hydraulic flow field in the aquifer and the stress caused by pumping of the deep extraction well. It is important to note that this portion of the plume is well within the model predicted capture zone of the deep extraction well (Figure 3-14) (AFCEE 2004a).

The eastern boundary is monitored at four locations (69MW1271, 69MW1312, 69MW1313, and 69MW1411) (Figure 2-3, Table 3-3). Based on recommendations in the final 2004 SPEIM report (AFCEE 2004a), monitoring wells 69MW1312 and 69MW1313 were added to the SPEIM program to address uncertainty in the delineation of the eastern boundary of the plume. Groundwater samples from the eastern boundary wells either did not contain EDB in 2004 and 2005, or contained EDB at concentrations below the

MMCL of 0.02 µg/L. Based on the sample results at 69MW1313, the eastern boundary of the plume has been redefined approximately 375 feet to the west of the prior delineation that was presented in the final 2004 SPEIM report.

The western boundary of the northern portion of the plume is monitored at three wells (69MW1311, 69MW1404, and 69MW1416). Similar to 69MW1312 and 69MW1313 discussed above, 69MW1315 was added to the SPEIM program to address uncertainty in the delineation of the southwestern boundary of the plume. EDB concentrations in groundwater sampled from this well increased from 1.47 µg/L in September 2004 to 1.62 µg/L in April 2005. Consequently, the southwestern boundary of the plume has been revised based on the data collected at 69MW1315 (Figure 2-3). These results are further discussed in the development of the 2006 plume shell in Section 3.2.1.3. Based on modeling predictions presented in the final FS-28 2004 SPEIM report (AFCEE 2004a), the portion of the aquifer monitored by 69MW1315 is within the capture zone of the deep extraction well. To further define the western extent of the plume in this area, monitoring of existing wells are recommended in Section 5.3.3.

Monitoring wells 69MW1303A (mid-screen elevation -174 ft msl) and 69MW1303B (mid-screen elevation -215 ft msl) are located approximately 140 feet south of the deep extraction well, but are believed to be within the capture zone of the deep extraction well based on model predictions (AFCEE 2004a). During this investigation EDB concentrations at 69MW1303A decreased from 0.018 µg/L in May 2004 to nondetect in September 2004, and increased to BRL during April and September 2005 (Table 3-3). Generally EDB concentrations in samples collected from 69MW1303A have shown a decreasing trend since 1997 (AFCEE 2004a). This well is screened adjacent to the bottom of the screened interval of the deep extraction well screen (Figure 3-8 and Figure 3-9). During this investigation, EDB concentrations at 69MW1303B were BRL during May and July 2004, decreased to nondetect in September 2004, increased to 0.022 µg/L in April 2005 and decreased to 0.014 µg/L during September 2005 (Table 3-3).

The area of the plume between the deep extraction well and the SWP system is monitored at five wells: 69MW1317A,B,C and 69MW1285A,B (Figure 2-3). Monitoring well 69MW1317A (mid-screen elevation –142 ft msl) is located approximately mid-way between the deep extraction well and the SWP system. Based on predictions using the FS-28 groundwater model, this location is downgradient of the deep extraction well capture zone but within the capture zone of the SWP system (AFCEE 2004a). In March 2005, AFCEE installed 69MW1317C (mid-screen elevation -59.7 ft msl) to monitor EDB concentrations identified during the collection of groundwater vertical profile data at 69DP0109 in August 2004. EDB was detected at concentrations above the MMCL of 0.02 µg/L at 69DP0109 in vertical profile samples collected between -45 ft msl and -85 ft msl (Figure 3-9 and Appendix E). The maximum EDB concentration (0.063 µg/L) was detected from the sample interval of -55 to -65 ft msl. EDB was not detected in samples from 69MW1317A or 69MW1317B,C except during July 2004 and August 2005, respectively, when concentrations were BRL (Table 3-3). The data collected at the monitoring wells screens since the installation of the direct push boring suggests the EDB detected during the vertical profiling at 69DP0109 in August 2004 has migrated south of this well cluster towards the SWP extraction system (Figure 3-9).

The monitoring well cluster 69MW1285A,B is located immediately north of the SWP system. The shallow well (69MW1285A, mid-screen elevation –34.4 ft msl) is used to monitor groundwater within the capture zone of the SWP system (AFCEE 2004a). Groundwater vertical profile data collected at 69DP0101 during May and June 2004 indicted the presence of EDB above the MMCL at mid-screen sampling elevations of -18 to -68 ft msl with concentrations ranging from 0.044 µg/L to 2.08 µg/L. In addition, a detection of 0.047 µg/L was reported at a mid-screen sample elevation -108 ft msl, and at a mid-screen elevation of -178 ft msl at a concentration of 0.049 µg/L (Figure 3-9 and Appendix E). The declining EDB concentrations measured in groundwater samples from 69MW1285A (i.e., 0.399 µg/L in May 2004 to 0.016 µg/L in September 2005) indicate the EDB mass detected during the installation of 69DP0101 between -18 and -68 ft msl has migrated south towards the SWP system (Figure 3-9). EDB was detected BRL or not detected in samples from the deeper well screen in this cluster (69MW1285B, mid-screen elevation -154 ft msl).

The declining EDB concentration trend at 69MW1303A presented in the 2004 SPEIM report (AFCEE 2004a), and the low EDB concentrations measured in the groundwater samples from this well cluster during this investigation, indicate that the northern portion of the plume is being captured by the deep extraction well. Additionally, the vertical profile data collected from 69DP0101 and 69DP0109, and the monitoring data collected from 69MW1285A,B; and 69MW1317A,B,C support the conclusion that the portion of the plume migrating towards the SWP extraction system is no longer being supported by EDB contaminated groundwater from the northern portion of the plume.

As part of the 2004 and 2005 FS-28 SPEIM program, the CWSW and two associated sentry wells are sampled. The CWSW is located near the western boundary of the FS-28 plume (Figure 2-3) and is screened at approximately –20 to -30 ft-msl. The top of the FS-28 plume is located approximately 70 feet below the CWSW. Pre-treated water from the CWSW (69PWS40960) remained nondetect for EDB based on monthly sampling conducted between April 2004 and February 2005 (Table 3-3). Since sampling began in 1997, EDB has never been detected in samples from this supply well.

The CWSW sentry wells (69MW1279B,C), located about 140 feet northeast and hydraulically upgradient of the CWSW, are screened from -62.8 to -67.8 and –103.0 to -108.0 ft msl, respectively. EDB was not detected in groundwater samples collected from 69MW1279B, the shallower of the two monitoring wells. However, in the deepest well in the cluster (69MW1279C, screened at a depth approximately 70 feet below the CWSW) EDB was detected at concentrations that ranged from 0.012 to 0.036 µg/L. Table 3-3 shows that only two of 17 samples contained EDB at concentrations equal to or greater than the MMCL of 0.02 µg/L. The range of EDB concentrations detected at 69MW1279C (Table 3-3) are similar to the range of concentrations observed in the past (AFCEE 2004a). The data collected from the CWSW and the shallow monitoring well (69MW1279B) support the conclusion the FS-28 plume is not impacting the CWSW.

In-Plume Monitoring Lateral To and Immediately Downgradient of the SWPs

Monitoring of the plume cross-gradient and immediately downgradient of the SWPs is achieved by sampling five locations: 69MW1291A, 69PZ1291A,B; 69MW1294, and 69MW1296A (Figure 2-3). Monitoring well 69MW1291A, with a 5-foot screen interval centered at -83.5 ft msl, is located approximately 20 feet west of the SWP system. EDB was not detected in any of the samples collected from 69MW1291A (Table 3-3). EDB was not detected in samples collected from 69PZ1291A, which has a 5-foot screen interval centered at 16.5 ft msl. However, EDB was detected in 69PZ1291B and the concentration decreased from 0.368 µg/L (May 2004) to BRL (September 2005). This well consists of a 5-foot screen centered at -18.5 ft msl, suggesting that the base of the FS-28 plume at this location has risen within the aquifer, possibly due to the hydraulic stress applied by the SWP system. This conclusion is supported by the elimination of EDB detections in 69MW1291A (mid-screen elevation -83.5 ft msl and which is screened approximately 65 feet deeper than 69PZ1291B) after May 1999, one month after the startup of the SWP system. EDB has not been detected in 69MW1291B since sampling began in 1999 (AFCEE 2004a). The vertical depiction of the plume at this location is shown on Figure 3-9.

Monitoring well 69MW1296A is screened deeper in the aquifer (5-foot screen centered at approximately -144 ft msl) and is located approximately 285 feet west of the SWP system (Figure 2-3). EDB was not detected at 69MW1296A (Table 3-3).

Monitoring well 69MW1294 is located approximately 120 feet southwest of the southern end of the SWP system, and is relatively shallow (mid-screen elevation -18 ft msl) with a well screen approximately 30 feet deeper than the SWP screens (Figure 2-3). EDB concentrations were below the MMCL of 0.02 µg/L at this well (Table 3-3).

3.2.1.2 Downgradient of the Treatment System

As a result of the increased pumping rate at 69EW0001 that began in April 2003 (AFCEE 2003b), the capture zone of the deep extraction well has expanded, and the monitoring and vertical profile data suggest that the plume north of 69EW0001 is being captured.

Accordingly, the uncaptured portion of the FS-28 plume downgradient of the deep extraction well appears to have become detached (Figure 3-9).

The leading edge of the plume was monitored and characterized using data collected from 26 monitoring wells and piezometers (69PZ0100, 69PZ0101, 69MW1286, 69MW1297, 69MW1298, 69PZ1298A,B; 69MW1300A,B; 69PZ1300A,B; 69MW1301, 69PZ1301A,B; 69MW1302, 69PZ1302A,B; 69MW1306A,C; 69MW1308, 69MW1308A,B; 69PZ1309A,B; 69MW1318A, and 69PZ1318) (Figure 2-3). In addition to the monitoring data collected from wells and piezometers, groundwater vertical profile data were collected from 25 direct push and three sonic drilling locations during the investigation.

Analyses of these data indicate the uncaptured portion of the plume has two distinct lobes: one relatively shallow and one relatively deep. The shallow lobe is approximately 3,200 feet long and is located between an elevation of approximately 6.7 and -54.5 ft msl (Figure 3-12). The shallow lobe is approximately 20 feet thick at the trailing edge (69DP0103) and increases to approximately 27 feet thick at 69DP0113, and narrows to less than 10 feet thick at the leading edge (69DP0123). This lobe contains a maximum EDB concentration of 0.381 µg/L detected at the southwestern edge of the Augusta Bog at 69DP0113 (Figure 3-10, Appendix E). The shallow lobe extends from the southwest corner of the Lower Baptiste Bog to just south of the intersection of Turner Road and Hidden Pond Way (Figure 3-9, Figure 3-10, Figure 3-11, and Figure 3-12). Based on the groundwater flow data presented in Section 3.1 and the general distribution of EDB concentrations greater than the MMCL, the shallow lobe is migrating in a south-southeasterly direction toward the Coonamessett River. However, due to the relatively low EDB concentrations and mass in this portion of the plume, EDB has not been detected in the river.

The deep lobe of the plume is approximately 3,400 feet long, located between an elevation of -76 and -183 ft msl, has an average thickness of approximately 70 feet, and contains EDB at a maximum concentration of 4.05 µg/L in the trailing edge of the uncaptured portion of the plume (i.e., 69DP0102), and decreases to a maximum

concentrations of 0.193 µg/L at the leading edge (i.e., 69DP0131) (Figure 3-9, Appendix E). The deep lobe of the uncaptured portion of the plume is migrating in a southerly direction within a sandy aquifer unit below a siltier layer located at an elevation of approximately -70 ft msl. A cross-sectional depiction of the shallow and deep plume lobes, approximately perpendicular to groundwater flow, is shown on Figure 3-10 and Figure 3-12.

Monitoring well 69MW1318A (mid-screen elevation –130 ft msl) is the northern most well that is screened within the deep lobe of the uncaptured portion of the FS-28 plume. EDB concentrations have decreased below the 3.7 µg/L reported in December 2003 (AFCEE 2004a) to 0.209 µg/L in September 2005. The recent decrease in the EDB concentration at this well is a reversal in the trend observed in the 2004 SPEIM report (AFCEE 2004a) indicating the higher EDB mass may have migrated downgradient of 69MW1318A.

Monitoring well 69MW1300A (mid-screen elevation -1.3 ft msl) is the northernmost well screened within the shallow lobe of the plume, and piezometer 69PZ1302A (mid-screen elevation 9 ft msl) is the southernmost well currently monitored under the SPEIM program. The EDB concentration at 69MW1300A increased from nondetect to 0.336 µg/L between April 2004 and July 2005, and decreased to 0.162 µg/L in September 2005. EDB was detected at a concentration of 0.027 µg/L at 69PZ1302A during August 2005. This result was similar in magnitude of the EDB concentration measured in the vertical profile sample collected from a mid-screen elevation of 3.2 ft msl at 69DP0113 (0.034 µg/L) located approximately 25 feet west of 69PZ1302A during December 2004 (Figure 2-1 and Figure 3-10, Appendix E). Monitoring well 69MW1300B (mid-screen elevation -76.4-ft msl) is screened just above the deep lobe of the plume. During this investigation, EDB was either not detected or at BRL concentrations. These data indicate that the plume is migrating below the well screen at 69MW1300B (Figure 3-9).

Monitoring wells 69MW1306A (mid-screen elevation -81.8 ft msl) and C (mid-screen elevation -117.8 ft msl) are currently the most southern and the most downgradient wells monitored under the SPEIM program that are screened within the deep lobe of the

uncaptured portion of the plume. EDB concentrations detected in 69MW1306A ranged from 0.015 µg/L in April 2004 to 0.507 µg/L in September 2005, and was BRL in 69MW1306C during November 2005. The EDB concentrations measured at 69MW1306A and C in September 2005 were not consistent with the vertical profile data collected at 69DP0104 during June 2004 (Figure 3-9, Table 3-3, Appendix E). These results show the heterogeneity of the distribution of EDB within the deep lobe of the plume.

Additionally, to determine if the shallow lobe of the uncaptured portion of the FS-28 plume was discharging to the western ditch of the East Thompson cranberry bog, 16 shallow groundwater samples were collected on a one-time basis in August 2005 from approximately one to two feet below the bog ditch using a push-point sampler (Figure 2-1). EDB was not detected in any of these samples. Surface water was also sampled for EDB at four locations: 69SW4003, 69SW4004, 69SW4005, and 69SW4006 within the western bog ditch during August 2005. EDB was not detected at any of these surface water samples. Additionally, groundwater vertical profiling was conducted at three locations (i.e., 69DP0120, 69DP0121, and 69DP0122) along the western perimeter road of the East Thompson Bog (Figure 2-1). EDB was not detected in any of these vertical profile samples (Appendix E). Therefore, based on an evaluation of these data, the plume does not appear to be discharging to the western ditch of the East Thompson cranberry bog.

3.2.1.3 Plume Shell

The 2006 FS-28 EDB plume shell is shown in Figure 3-13 and Figure 3-14. Assuming an aquifer porosity of 30 percent, the volume of EDB contaminated groundwater and the EDB mass in the 2006 plume shell are 2.60 x 10^8 cubic feet (ft^3) and 5.41 pounds (lbs), respectively. This contaminant mass is spatially distributed such that 4.99 lbs (or 92 percent of the total plume mass) of EDB in the plume is located north of 69EW0001 in the main FS-28 plume, 0.008 lbs (or 0.15 percent) between 69EW0001 and the SWP system, and 0.42 lbs (or 8 percent) south of the SWP system (uncaptured portion). This compares to a plume volume and mass of 2.25 x 10^8 ft^3 and 5.91 lbs, respectively, for the

2003 version of the plume shell (also shown on Figure 3-13 for comparison along with the 2001 version of the FS-28 plume shell).

North of deep extraction well 69EW0001, the plume shell mass has decreased and the volume has increased compared to the 2003 plume shell version. Samples collected from direct push locations 69DP0105, 69DP0106, and 69DP0108 have increased the vertical thickness of the plume shell immediately north of the deep extraction well. The western boundary of the 2006 plume shell was extended approximately 400 feet westward from just north of the deep extraction well to 69MW1416 because of the EDB detection at 69MW1315 (1.62 µg/L in April 2005). Monitoring well 69MW1315 was not sampled for the 2003 plume shell update. Also, nondetect samples from well 69MW1313, during 2004 and 2005, which was not sampled for the 2003 plume shell update, has redefined the eastern plume shell boundary (approximately 375 feet westward) in the vicinity of that well.

In the vicinity of the SWP system, the 2006 plume shell has less contaminant mass and volume than the 2003 version of the plume shell. These reductions in plume mass and volume can most likely be attributed to the operation of the SWP system. The most recent samples collected in 2005 from wells 69MW1285A,B and some of the shallow well points have lower EDB concentrations than samples collected for the 2003 plume shell.

South of the SWP system, samples collected from the drilling locations have refined the delineation of the uncaptured portion of the plume resulting in less mass and more volume in this portion of the 2006 plume shell when compared to the 2003 plume shell. The mass in the uncaptured portion of the 2003 plume shell is based on two monitoring well sample results, 3.7 µg/L at 69MW1318A and 0.26 µg/L at 69MW1306A (AFCEE 2004a). The mass of the 2006 plume shell was based on the monitoring well and drilling data collected in support of this plume update and detailed in Section 3.3. The 2006 plume shell extends more than 1,500 feet further south than the 2003 plume shell, is narrower, and has an additional shallow lobe that extends southeastward toward the Coonamessett River.

In summary, a comparison of the 2006 and 2003 plume shells presented on Figure 3-13 clearly shows a different representation of the spatial distribution and magnitude of EDB concentrations in the FS-28 plume. The changes are mainly due to the acquisition of additional data in the core of the plume north of 69EW0001 and in the uncaptured portion of the plume, and the successful operation of the FS-28 ETD system. It should be noted that Figure 3-14 also shows the 2006 plume shell and model-predicted capture zones for the FS-28 ETD system presented in the final 2004 SPEIM report (AFCEE 2004a).

3.2.2 Surface Water

During 2005, 27 Coonamessett River and associated bog ditch locations were monitored at various frequencies (Figure 2-3). Surface water quality was also monitored near recreational beaches at three ponds (i.e., Coonamessett Pond, Round Pond, and Jenkins Pond) in the vicinity of the FS-28 plume as part of the recreational beach monitoring program. EDB was not detected in surface water samples collected with the exception of samples collected from two Augusta Bog locations (69SW0060 and 69SW2001) between June and October 2005 (Table 3-4).

Surface water location 69SW2001 was sampled to monitor water quality in the northern portion of the Augusta bog. Surface water sampled between June and October 2005 contained EDB at a maximum concentration of 0.012 µg/L, which was below the human health screening level risk-based concentration (for a 10^{-3} cancer risk) of 7.71 µg/L (AFCEE 2003b), the ecological screening-level benchmark of 31 µg/L (AFCEE 1998a) and the MMCL of 0.02 µg/L. Location 69SW0060 was sampled to monitor the water quality of surface water flowing out of the Augusta Bog and into the Augusta Bog irrigation pond. EDB was only detected in surface water sampled from this location on 13 June 2005 at a concentration BRL. Prior to June 2005, EDB has not been detected in surface water samples collected from 69SW0060 or 69SW2001 since February 1999. During July and August 2005 surface water was also sampled from the Augusta Bog irrigation pond. Samples were collected from the surface of the pond and from approximately 15 feet below the pond surface. EDB was not detected in the samples collected from the irrigation pond.

4.0 CONCEPTUAL SITE MODEL UPDATE

4.1 PREVIOUS CONCEPTUAL SITE MODEL

The FS-28 plume was characterized in 1997 (AFCEE 1997). At that time a conceptual site model (CSM) was developed and described the FS-28 plume as a detached plume that originated at an unidentified source on the MMR. The data indicated that the plume was migrating southward, flowing under the western arm of Coonamessett Pond (between approximately -70 and -250 ft msl). To the south of Hatchville Road, the plume was believed to rise in the aquifer to discharge to the Coonamessett River and associated cranberry bogs. However, based on subsequent monitoring data, the entire vertical extent of the EDB plume does not appear to upwell to the river and bogs.

Groundwater modeling presented in the *Final Fuel Spill-28 2002 Annual System Performance and Ecological Impact Monitoring Report* (AFCEE 2003b) indicated that after startup of the remedial system, a portion of the plume located south of the influence of the ETD system (between approximately -70 and -150 ft msl) would continue to migrate south, converge into a narrow plume, and then rise gradually in the aquifer to ultimately discharge to the Coonamessett River north of Pond 14. Modeling simulations presented in the final 2004 FS-28 SPEIM report showed a similar fate for this uncaptured portion of the plume (AFCEE 2004a).

The leading edge of the uncaptured portion of the plume was defined by EDB detections in groundwater screening samples from 69MW1300 and by nondetects in groundwater screening samples at downgradient borings 69MW1302, 69MW1308, and 69MW1306. Based on data collected through March 2004, the extent of the uncaptured portion of the plume was revised to reflect higher EDB concentrations detected at 69MW1318A (3.7 µg/L in December 2003) (AFCEE 2004a). This increase in EDB was attributed to the migration of EDB formerly upgradient of 69MW1318A but not within the 69EW0001 capture zone. In addition, detections of EDB at 69MW1302 and 69MW1306A indicated that the leading edge of the uncaptured portion of the plume had migrated south of these monitoring wells. At that time, no groundwater monitoring points existed south of the

69MW1306 well cluster. The increase in EDB concentrations observed at 69MW1306 led to a recommendation to investigate the area south of Thomas B. Landers Road (AFCEE 2004a).

4.2 REVISED CONCEPTUAL SITE MODEL

The data evaluated for this FS-28 plume update indicate the plume north of 69EW0001 and the shallow portion of the plume in the vicinity of the SWP system continue to decrease in mass with continued operation of the ETD system. Evaluation of the monitoring and investigation data presented in this technical memorandum has led to a refinement of the depiction of the plume north of 69EW0001. This refinement includes a general westward shift in the delineation of the plume north of 69EW0001 and an overall reduction in EDB contaminant mass based on generally lower EDB concentrations.

The uncaptured portion of the plume, located south of the influence of the ETD system, was characterized using drilling and monitoring data collected in support of this plume update. In particular, the focus of this effort was to determine the extent of the plume located south of Thomas B. Landers Road which was previously uncharacterized. The new data collected during the drilling investigation indicate that this uncaptured portion of the plume appears to bifurcate into a deep and shallow lobe. The shallow lobe of the plume appears to be migrating south-southeast in a sandy part of the aquifer toward (and possibly discharging to) the Coonamessett River north of Pond 14. The southern extent of this shallow lobe is relatively thin (10 to 30 feet thick vertically), is approximately 20 to 50 feet below ground surface, and contains relatively low EDB concentrations (i.e., less than 0.1 µg/L). Therefore, based on the current characterization of this shallow lobe, it is not likely that EDB will be detected in surface water samples collect from the Coonamessett River between Thomas B. Landers Road and Pond 14.

The new characterization data indicate that the deep leading edge lobe is also migrating in a sandier portion of the aquifer (between -70 and -150 ft msl). Lithologic information indicates that the sandy portions of the aquifer that contain the shallow and deep lobes are separated by a silty sand. The deep lobe appears to remain at depth in the aquifer

(in excess of 100 feet below ground surface) below the silty sand and continues to migrate south, parallel to and west of the Coonamessett River. The deep lobe appears to be migrating on a more southerly trajectory than the shallow lobe. The leading edge of the deep lobe is located south of 69DP0131 (Hidden Pond Way) where the top of the plume is encountered approximately 140 feet below ground surface, is approximately 70 feet thick, and approximately 200 feet wide. The deep lobe appears to remain at depth due to the combination of a relatively strong component of horizontal flow and a slightly downward vertical component of hydraulic gradient within this portion of the aquifer. The presence of the silty sand unit may also be keeping this lobe deeper in the aquifer. The deep lobe remains relatively thick (vertically) along its identified length and is expected to continue to travel in a southerly direction, at its current depth in the aquifer, until it encounters a region of upward vertical gradients or a change in lithology (e.g., a discontinuity in the silty sand unit). However, there is considerable uncertainty in the ability to predict future migration of this deep lobe due to a lack of data south of its current location.

4.3 ASSESSMENT OF PRIVATE WELLS IN THE STUDY AREA

This updated CSM, including the revised delineation of the uncaptured portion of the plume, has warranted a re-assessment of the potential presence of private water supply wells in the vicinity of the uncaptured portion of the plume. AFCEE previously assessed the area for private wells in 1997. This prior assessment resulted in residences in this area on Hidden Pond Way, Turner Road, and Thomas B. Landers Road (Figure 2-1) being connected to the public water supply system by AFCEE in 1997. Therefore, there is no current risk of exposure to the plume through the use of private wells as a result of the revised plume delineation presented in this technical memorandum.

A recent assessment of private wells south of Sandwich Road (i.e., downgradient of the leading edge of the uncaptured portion of the plume) has identified several residences that may have private wells located hydraulically downgradient of the newly defined uncaptured portion of the plume. None of the residences identified are located closer than 600 feet to the plume as currently delineated. The residents that may have private

drinking water wells have been contacted by AFCEE and sampling of these private wells for EDB analysis is underway for those residents who requested sampling. The results of the residential well sampling will be presented to the regulators when the data are available.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The following section presents the conclusions drawn from the data evaluated in this technical memorandum, assesses areas of uncertainty, and presents recommendations.

5.1 CONCLUSIONS

The spatial distribution of EDB contamination in the FS-28 plume has been updated based on a combination of monitoring data collected under the SPEIM program in 2004 and 2005 and new characterization data collected north of 69EW0001 and at the leading edge of the plume. In addition, the new characterization data has led to a better understanding of the hydrogeology south of Thomas B. Landers Road allowing for a revised FS-28 CSM.

The main conclusions drawn from this plume update are:

- The EDB concentrations in the plume within the capture zone of the FS-28 ETD system continue to show a general overall decreasing trend, primarily due to the operation of the remedial system. However, based on data collected during direct push drilling investigation, the plume upgradient of the deep extraction well is thicker than previously characterized.
- The western boundary of the plume north of the deep extraction well has been expanded approximately 400 feet to the west due to EDB detections at 69MW1315 (that was not previously monitored). Groundwater modeling performed in 2004 indicates the contaminant mass added on the western boundary of the plume is within the capture zone of the deep extraction well.
- The eastern boundary of the plume north of the deep extraction well has been redrawn approximately 375 feet west of its former location based on monitoring results at 69MW1313 (EDB not detected when sampled in 2004 or 2005).
- The nature and extent of the uncaptured portion of the plume has been successfully characterized using data collected during a direct push and conventional drilling program. The uncaptured portion of the plume is approximately 1,500 feet farther south than previously portrayed based on data collected through March 2004 (AFCEE 2004a).
- The uncaptured portion of the plume appears to be completely detached from the main plume to the north and consist of two distinct lobes: (1) a shallow lobe that is approximately 3,200 feet long, located between an elevation of approximately 6.7 and -54.5 ft msl, and containing a maximum EDB concentration of 0.381 µg/L; and

(2) a deep lobe approximately 3,400 feet long, located between an elevation of approximately -76 and -183 ft msl, and containing EDB concentrations as high as 4.05 µg/L.

- The shallow lobe appears to be migrating in a south-southeasterly direction towards the Coonamessett River. Because of the relatively low EDB concentrations in the shallow lobe, EDB is not expected to be detected in the Coonamessett River surface water if this shallow lobe discharges (or is discharging) to the river.
- The deep lobe is migrating in a southerly direction in a sandier portion of the aquifer beneath a silty sand layer that approaches 40 feet thick in some areas and separates the shallow and deep lobes of the plume.
- The mass of EDB in the 2006 plume shell is estimated to be 5.41 lbs. The majority of this EDB mass (approximately 5 lbs) remains upgradient and within the capture zone of the deep extraction well. A small portion of the EDB mass (approximately 0.008 lbs) remains within the capture zone of the SWP extraction system, and the newly characterized uncaptured portion of the plume contains approximately 0.42 lbs of EDB.
- To date, the hydraulic conditions influencing the migration of the plume are only known north of 69DP0131 (i.e., the intersection of Hidden Pond Way and Turner Road). Therefore, predictions regarding the fate and transport of the shallow and deep uncaptured portions of the plume south of Hidden Pond Way cannot be made at this time.
- Because of the apparent complex hydrogeology and hydraulic flow field south of Thomas B. Landers Road and the relatively narrow footprint of both the shallow and deep lobes of the plume, continued assessment of plume migration in this area will be based on hydraulic and chemical monitoring data collected at a network of wells and piezometers in the vicinity of the leading edge of the plume rather than relying on groundwater flow and transport modeling.
- There is no current risk of exposure to the plume as a result of the revised plume delineation because residences in the immediate vicinity of the plume were connected to the public water supply system in 1997 by AFCEE. However, several residences located to the south of the current delineation of the uncaptured portion of the plume have been identified as potentially having private wells that supply potable water. AFCEE has contacted these residents and is currently arranging to have these wells sampled for those residents who requested sampling.

5.2 UNCERTAINTIES

The data evaluation presented in this technical memorandum has identified uncertainties associated with: (1) the western boundary of the plume north of the deep extraction well; (2) the northwestern boundary of the deep lobe of the uncaptured portion of the plume; (3) the southeastern boundary of the shallow lobe of the uncaptured portion of the plume;

and (4) the ability to predict the future migration of both the shallow and deep lobes of the uncaptured portion of the plume. As previously noted, the leading edge investigation is ongoing at the time of the preparation of this technical memorandum. It is anticipated that the data collected during the ongoing investigation will aid in addressing the uncertainties identified for the uncaptured portion of the plume. Actions to address the uncertainty associated with the western boundary of the plume upgradient of the deep extraction well are recommended in Section 5.3 below.

5.3 RECOMMENDATIONS

5.3.1 Leading Edge Investigation

The ongoing leading edge investigation has been designed to collect data to address the uncertainties discussed above associated with the characterization of the uncaptured portion of the plume. Specifically, drilling has either been completed or is planned in the following areas:

- To define the northwestern boundary of the uncaptured portion of the plume, groundwater profiling was completed and piezometers were installed during April 2006 at the location on Thomas B. Landers Road west of the Augusta Bog (designated 69PZ0023A,B/69MW0023). Since these data were collected concurrent with the preparation of this technical memorandum, these data were not included in this evaluation.
- Three hydraulic monitoring locations are being installed between Jenkins Pond and Pond 14. One location has been completed on Sandwich Road (designated 69MW0025A,B/69PZ0025) during April 2006 using sonic drilling and included groundwater vertical profiling, the collection of soil samples and the installation of monitor wells and a piezometer. A direct push location has also been completed on Pinecone Lane (designated 69PZ0024A,B) and included groundwater vertical profiling and the installation of piezometers. The third location south of Round Pond (on Round Pond Drive and designated 69PZ0026A,B) is yet to be completed at the time of preparation of this technical memorandum.
- A direct push location (designated 69DP0135) is planned at the intersection of Sandwich Road and John Parker Road to provide additional aquifer characterization data.
- The need for the proposed monitoring well at the Cape Cod Cooperative Campground will be determined following the evaluation of the hydraulic data collected from the uncaptured portion of the plume,

- Slug testing will be conducted in newly installed screens within and in the vicinity of the current leading edge of the uncaptured portion of the plume to provide estimates of aquifer hydraulic conductivity at locations south of Thomas B. Landers Road. The locations for the slug testing will be determined following the completion of the ongoing investigations and after evaluation of hydraulic data collected from the new piezometers.

The proposed drilling locations are shown on Figure 5-1. Data collected at these locations will be (or have been) presented during technical update meetings.

5.3.2 Hydraulic Monitoring

Recommendations related to hydraulic monitoring are as follows:

- The SPEIM hydraulic monitoring network should be optimized in light of the new characterization data presented in this technical memorandum. The new FS-28 SPEIM hydraulic network will be presented in a project note. The objective of the network optimization will be to select hydraulic monitoring locations that will provide data necessary to:
    1) Evaluate the flow field that is influenced by the operation of the FS-28 ETD system using the residual analysis method (AFCEE 2004c). This evaluation will be used to verify the existing FS-28 groundwater model-predicted capture of the EDB plume by the deep extraction well and the SWP system.
    2) Assess the groundwater flow field that influences the migration of the uncaptured portion of the FS-28 plume (i.e., south of the influence of the FS-28 ETD system). As noted in the conclusions presented in Section 5.1, the fate of the uncaptured portion of the plume should be assessed using measured data rather than relying on groundwater modeling due to indications that the groundwater flow field in this area is complex. The network of wells and piezometers in this area is currently being improved as described in Section 5.3.1.
- Upon completion of the drilling at the leading edge of the plume and the redesign of the hydraulic monitoring network, a synoptic groundwater level survey is recommended to provide a comprehensive dataset that can be used to evaluate the flowfield within both the captured and uncaptured portions of the plume.

5.3.3 Chemical Monitoring

The proposed SPEIM groundwater chemical monitoring network is presented in Table 5-1 and locations are shown on Figure 5-2. Specifically, the following changes will be incorporated in the SPEIM groundwater monitoring program:

- Monitoring well 69MW1316 will be sampled for EDB once every two years using a diffusion sampler to monitor the western boundary of the plume upgradient of the deep extraction well.
- Monitoring wells located outside of the plume boundary of the northern plume lobe will be sampled for EDB once every two years using diffusion samplers, with the exception 69MW1501. The monitoring frequency for 69MW1501, an irrigation well sentry well, is proposed to be reduced from monthly during the growing season (March through October) to four times during the growing season April, June, August and October, contingent based on concurrence by the property owner.
- Monitoring wells located within the northern lobe of the plume and north of the western arm of Coonamessett Pond will be sampled for EDB once every two years using diffusion samplers.
- Monitoring wells located within the northern lobe of the plume and south of the western arm of Coonamessett Pond will be sampled for EDB annually using diffusion samplers, with the exception of CWSW sentry wells 69MW1279B and 69MW1279C which will be sampled quarterly for EDB analysis.
- Monitoring wells 69MW1419 and 69MW1271 will be eliminated from the SPEIM program because the plume has migrated south of these locations and the trailing edge of the plume is currently monitored at 69MW1272 and 69MW1416.
- Piezometers 69PZ0005B, 69PZ0019B, 69PZ1298A, 69PZ1300A, 69PZ1302A, and 69PZ1308A will be sampled semiannually for EDB analysis to monitor the shallow lobe of the uncaptured portion of the plume.
- Piezometer 69PZ0017A and monitoring wells 69MW0012A, 69MW0023, and 69MW0025A,B will be sampled semiannually for EDB analysis to monitor the deep lobe of the uncaptured portion of the plume.

Because the CWSW has been connected to the Crooked Pond water treatment plant, the well will no longer be sampled for EDB and the Town of Falmouth agreed to reduce the monitoring frequency for the two upgradient sentry wells (69MW1279B,C) from monthly to quarterly.

The proposed SPEIM surface water monitoring network is presented in Table 5-2 and locations are shown on Figure 5-3. Recommended changes are as follows:

- The existing 20 surface water locations included in the chemical monitoring network north of Sandwich Road (Figure 5-3) will be monitored monthly during the cranberry growing season (March through October). Most of these locations are currently monitored monthly, however two locations (69SW0049 and 69SW2007) have been monitored less frequently (i.e., quarterly or annually) in the past. Monitoring

frequency will be increased to monthly between March and October at these locations.

- The following four surface water locations south of Pond 14 will be added to the SPEIM program and will be sampled for EDB annually in September prior to the cranberry harvest: 69SW0051, 69SW0052, 69SW2008, and 69SW2009.
- Surface water location 69SW0065 (located downstream of bubbler #1) will continue to be monitored for water quality parameters on a quarterly frequency. This location is monitored to assess the potential ecological impacts associated with the discharge of treated water to the Coonamessett River from the ETD system.

Surface water samples will continue to be collected for EDB analysis near recreational beaches at Coonamessett Pond, Deep Pond, Jenkins Pond and Round Pond during April/May and July.

5.3.4 Residential Well Sampling

One residence located approximately 600 feet south of the shallow lobe, and several residences located approximately 1,600 feet south of the current leading edge of deep lobe, may have private wells that supply potable water. These residents have been contacted by AFCEE and sampling of these private wells for EDB is underway for those residents who requested sampling. AFCEE plans to add these locations to the residential well monitoring program.

6.0 REFERENCES

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